MODELING THE DISTRIBUTION AND ABUNDANCE OF SPOTTED SEATROUT: INTEGRATION OF ECOLOGY AND GIS TECHNOLOGY TO SUPPORT MANAGEMENT NEEDS

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ABSTRACT

The spotted seatrout, *Cynoscion nebulosus*, is one of the most preferred recreational sport fish in northern Gulf of Mexico estuaries. Management of most recreational and commercial species has been based on stock surplus or recruitment models. Recent advances in the integration of ecological modeling and geographic information system (GIS) technology promote the ability to predict seatrout relative abundance and distribution based on their habitat affinities and encourage an ecosystem approach to resource management. The integration of ecological models and GIS technology provides a "seascape" view (maps) of habitat suitability in geographic space through time. Modeling approaches vary based on data availability. A continuum of approaches has been developed to evaluate the efficacy of suitability index derivation. The continuum was based along a progression of data type, requirement, availability, reliability, and robustness. The range of approaches include reliance on qualitative literature review to the use of quantitative analysis of fisheries independent monitoring data. Managers can choose which approach adequately answers their management questions based on data availability and resource constraints. This chapter will discuss a suite of research approaches and modeling techniques to predict spotted seatrout distribution. In addition, the chapter will describe the concept of model transferability, where models developed from robust monitoring programs can be applied to systems lacking biological information.

INTRODUCTION

The spotted seatrout, *Cynoscion nebulosus,* is one of the most important recreational and commercial fishes in the northern Gulf of Mexico and southeast coast of the U.S. Approximately 68% of recreational anglers in the Gulf coast region target spotted seatrout as their fish of choice (LDWF, 2000). Over the past 15 years, commercial and recreational landings throughout Gulf coast estuaries were high, especially in Florida and Louisiana (Murphy et al., 1999). Spotted seatrout life history typically occurs within the fishes natal estuary (Moffett, 1961; Ingle et al., 1962; Iversen and Moffett, 1962; Topp, 1963; Beaumariage, 1964; Tabb, 1966; Overstreet, 1983; Chester and Thayer, 1990; Baker and Matlock, 1993). As such, spotted seatrout populations are almost exclusively affected by local fishing pressures and severe environmental events such as freezes (Murphy and Taylor, 1994).

Today, managers are increasingly faced with declining stocks and increasing pressure for management policy. Traditional management approaches tend to concentrate on surplus production, yield-per-recruit, and stock-recruitment models. However, the existing approaches and available data do not adequately support the policy making process. A key to developing a robust approach is to address increased understanding of biological systems nested within and driven by physical processes (Rothschild and Ault, 1992). It has become apparent that without an understanding of fishery habitats, communities, species interactions, and anthropogenic impacts, today's management strategies are basically reactive, rather than preventative (Rubec and McMichael, 1996).

Recent advances in technology, combined with increasing awareness of data needs, have promoted an ecosystem approach for fisheries management. Many scientific disciplines have been using geographic information systems (GIS) for years. Only recently has this technology become attractive to fisheries researchers and managers. A GIS is a data management and information analysis system that is able to capture, synthesize, generate, retrieve, analyze, and output spatial information (Haddad et al., 1996). GIS is often perceived as a reflection of its products, such as computer generated maps. A GIS is a computer system that can store and link non-graphic attributes or geographically referenced data with map features that allows information processing, such as modeling (Antenucci et al., 1989).

The Center for Coastal Monitoring and Assessment Biogeography Program (CCMA/BP) has been developing Habitat Suitability Models (HSM) using GIS to provide estuarine and marine resource managers a habitat assessment capability. This approach has been designed to produce a "seascape" representation of habitat suitability in space through time. A specific type of HSM's are Habitat Suitability Index models (HSI). HSI models are simple mathematical expressions for calculating a unitless index of habitat quality as a function of one or more environmental variables that define habitat quality for a particular species or life history stage (Brown et al., 1997). The underlying modeling approach was introduced by the U. S. Fish and Wildlife Service's (USFWS) Habitat Evaluation Procedures Program, whereby models resulted in a numerical index of habitat suitability ranging from 0.0 - 1.0. Models were based on the assumption that a positive relationship exists between the index and a habitat's carrying capacity for a given species (Schamberger, 1982). Our techniques have taken a considerable departure from USFWS methods by incorporating a GIS spatial component. This technique allows the visualization of environmental and/or biological data in geographic time and space. In addition, the BP has developed a continuum of approaches to define species suitability index (SI) values that when combined with GIS, comprise the HSI output (Figure 1). This continuum portrays the progression of approaches as it relates to data type, requirement, availability, reliability, and robustness (Coyne and Christensen, 1997). The simplest approach, which relies on scientific literature and expert knowledge, can be used to develop broad spatial and temporal species distribution maps or atlases (SAB, 1986). With sufficient habitat or environmental data, maps can be developed which portray species distributions in an environmental spatial framework. For example, the BP's Estuarine Living Marine Resources (ELMR) database contains monthly relative abundance information within a salinity zone framework for 153 species in 122 estuaries throughout the contiguous U. S. (Nelson and Monaco, 2000). If numerous environmental frameworks can be developed for a known area, HSI modeling can provide a more spatially explicit view of habitat quality (Brown et al., 2000). Spatially and temporally robust FIM data provides the necessary information to develop sophisticated modeling methods (e.g. multivariate, logistic regression) which can be used to quantify species habitat affinities (Rubec et al., 1999; Livingston et al., 2000; Clark et al., in review).

This chapter presents the methodology and results of two different approaches that examined habitat suitability for spotted seatrout in northern Gulf of Mexico estuaries. A qualitative habitat assessment was designed to investigate the feasibility of developing meaningful habitat suitability models in Pensacola Bay, Florida, where limited scientific data are available that would support more rigorous statistical models. Suitability indices were developed based on existing scientific literature and expert knowledge. In contrast, a quantitative assessment was designed for Charlotte Harbor, Florida, which examined three modeling methodologies. In addition, the concept of model transferability across Gulf of Mexico estuaries with similar geomorphologic and hydrological characteristics was addressed.

PENSACOLA BAY

Habitat suitability index models (HSI) were developed in Pensacola Bay, Florida, to examine the relationships between spotted seatrout distribution and hydrological and biological parameters. The intent was to produce a simple qualitative spatial model that could provide a habitat assessment capability which could be applied to a wide range of estuarine systems. Pensacola Bay was chosen as the test area because its hydrographic conditions were considered representative for most Gulfwide estuaries. For a more complete description of this study see Christensen et al. (1997).

Model Development

The first step in developing the HSI model was to conduct a comprehensive data and literature search. This was combined with an expert review process to identify the critical set of biological and environmental variables to include in the model. Salinity, water temperature, dissolved oxygen content, bathymetry, substrate type, and the presence or absence of submerged aquatic vegetation (SAV) and emergent wetland macrophytes (EV) were selected to model seatrout habitat suitability.

A species occurrence matrix (presence/absence) was developed in one-unit increments for each environmental parameter - salinity (ppt), water temperature (˚C), dissolved oxygen content (mg/l), depth (m), presence of SAV (i.e., *Halodule wrightii*), and presence of EV (i.e., *Spartina alterniflora*). These matrices enabled identification of critical values for suitability index (SI) values. SI's were derived under the assumption that all other parameters were held constant at, or near their optimum. Although interactions commonly occur, environmental parameters were classified independently. Under these assumptions, complete absence indicated zero suitability, and SI coefficients were set to zero.

Juvenile and adult spotted seatrout SI values were generated through an extensive literature search for documented tolerances to, and affinities along, each biological and environmental gradient (Reid, 1954; Stewart, 1961; Tabb, 1966; Copeland and Bechtel, 1974; Taniguchi, 1980; Peebles and Tolley, 1982; Lassuy, 1983; Kosteki, 1984; Johnson and Seaman, 1986; Van Hoose, 1987; Bryan et al., 1989; McMichael and Peters, 1989; Patillo et al., 1997). SI values previously developed by the U.S. Fish and Wildlife Service (USFWS, 1984) were used as baseline, where appropriate. Assigning SI's involved considerable expert knowledge and judgement and values may require adjustments based on biogeographic differences. Due to the lack of density data for SAV and EV, SI values were assigned based on the presence or absence of these habitats. Table 1 displays adult and juvenile SI values for the selected environmental variables.

Because the relationship between environmental and biological gradients and species distributions are inappropriate to quantify without a robust data set, variables were not weighted in a conventional manner. Variables were categorized as either critical or non-critical, based on their potential effect on seatrout distribution. A critical variable was defined as one exhibiting the potential to exclude a population if physiological tolerances are exceeded: salinity, water temperature, dissolved oxygen, and bathymetry. Critical variables were scaled from 0 - 1.0 and for any variable that scored a 0 the model would predict complete exclusion. Non-critical variables were defined as those that have an effect on species distributions; however, they are not independently limiting. Substrate type, and the presence or absence of SAV and EV were considered non-critical for this study. These variables were scaled from 0.2 - 1.0 and by scaling the SI's in this manner, we were able to weight the variables without using statistical methods to quantify the relationships.

Once SI values were developed, environmental GIS data grids were constructed to represent a spatial view of the environmental variables. Continuous data that vary along a gradient, such as bathymetry, dissolved oxygen, salinity, and temperature, were acquired from the Florida Department of Natural Resources and the Environmental Protection Agency's EMAP Program (FLDNR, 1991; USEPA, 1996). These data were then independently mapped by georeferenced (latitude/longitude) sampling stations. The point data, measured from irregularly spaced locations, were converted into continuous, contoured surfaces using a inverse distance weighting (IDW) method, then rasterized into a grid format (ESRI, 1996). A conceptual view of GIS grid development is shown in Figure 2. Each grid was created with the same coordinate system and cells among grids were aligned in geographic space to facilitate inter-grid processing. All grids had the same cell size of 1,000 m^2. At this resolution, each environmental grid map in Pensacola Bay consisted of approximately 37,000 cells. Each environmental grid was then categorized: salinity (Figure 3a) was mapped in 5 ppt increments (Orlando et al., 1993), water temperature (Figure 3b) in 2 ˚C isotherms (SAB, 1986) and, dissolved oxygen in 1 mg/l increments (SEA, unpublished data). Substrate was categorized using a modified Shepard's classification scheme (Shepard, 1954), and was classified as either sand, silt, or clay. The distribution of SAV and EV was documented by aerial photography and digitized by the USFWS (USFWS, 1986). SAV and EV grids were classified as either present or absent.

Models were run during four time periods to address seasonal fluctuations in seatrout distribution. Representative periods for the Pensacola Bay HSI model were determined by characterizing salinity conditions in the estuary. Seasonal depth-averaged salinity was modeled from a subset of field salinity data collected between 1970 and 1994 (Orlando et al., 1993). Consequently, salinity seasons consisted of four three month periods: high salinity (September - November), low salinity (February - April), increasing salinity (May - August), and decreasing salinity (December - January). These periods represent the typical salinity conditions experienced under average seasonal freshwater inflow conditions. Five ppt isohalines were developed to represent the typical range of salinity conditions experienced under average seasonal freshwater inflow. The isohalines shift seasonally due to environmental factors such as freshwater inflow, tides, evaporation, and wind (Orlando et al., 1993). Water temperature was contoured for the same months as the salinity seasons to ensure temporal uniformity in the models.

Arc/Info 7.03 GRID© module was used to conduct the HSI modeling. GRID supports cartographic spatial analysis using a high-level computation language. Thus, processing between grids utilizes a simple and efficient map-algebra calculation of numeric cell values. HSI values were calculated using a geometric mean for each cell across all grids:

Equation (1)

$$HSI = [\prod_{i=1}^{n} (v_i)]^{(1/n)}$$; where v_i = environmental variable, and n = number of variables in the model.

Optimum HSI values (1.0) are achieved if all environmental variable SI's within a cell are at optimum. Likewise, if any one variable SI is unsuitable (0.0) within a cell, the HSI model will indicate unsuitable habitat regardless of the SI value for all other variables. An example of the integration of SI values and grid maps to produce HSI models is shown in Figure 4. HIS values were categorized to simplify map interpretation: Unsuitable = 0.00, Low = 0.01 - 0.33, Moderate = 0.34 - 0.66, High = 0.67 - 0.99, and Optimum = 1.0.

HSI Model Results

Juvenile spotted seatrout HSI models exhibited great spatial and temporal sensitivity to fluctuating environmental parameters. Highest suitability values were observed in EV and SAV habitats during the increasing salinity season (May - August) when water temperatures were at an optimum level (Figure 5). We assumed that growth of spotted seatrout is temperature-dependent (Johnson and Seaman, 1986), with optimum temperatures for somatic growth and condition (K) consistently reported between 25 - 30

˚C (Tabb, 1958; Stewart, 1961; Taniguchi, 1980; Patillo et al., 1997). Juvenile spotted seatrout are abundant in vegetated habitats to avoid predation pressures (Johnson and Seaman, 1986; Chester and Thayer, 1990) and feed upon copepods, mysid and caridean shrimp, and post-larval penaied shrimp that are typically abundant in these habitats (Moody, 1950; Darnell, 1958; Adam et al., 1973; Overstreet and Heard, 1982; Hettler, 1989; Minello, 1999). Suitability was moderate in the non-vegetated habitats throughout the rest of the bay.

Low suitability was observed throughout the bay during the decreasing salinity time period (December - January), when temperatures declined to 10-14 ˚C. This does not indicate that juvenile trout are leaving the estuary; rather it is a comparison of suitabilities relative to the remaining salinity defined seasons. Spotted seatrout have been observed to move to warmer waters of deep channels and depressions to avoid thermal stress in the winter (Moody, 1950; Tabb, 1966). Moderate HSI values were observed bay-wide during the low (February - April) and high (September - November) salinity time periods as temperatures declined away from or increased towards the optima.

Similar patterns were observed in adult seatrout HSI distribution. Optimum and high suitability was predicted for shallow, vegetated habitats during the increasing and high salinity time periods. Optimum and high suitability zones were more extensive for adults compared to juveniles. Approximately 90% of the bay was considered high or optimum habitat for adult seatrout during these time periods (Figure 6).

Cooler temperatures during the decreasing (December - January) and low (February - April) salinity time periods resulted in medium or low suitability throughout the unvegetated portions of the bay. Vegetated habitats in the lower portion of the bay were ranked as highly suitable during the low salinity time period and medium during the decreasing salinity time period.

Model Validation

Due to the lack of consistent and robust FIM data for spotted seatrout in Pensacola Bay, Christensen et al. (1997) conducted a qualitative assessment to validate the spotted seatrout models. Local fisheries biologists and commercial fishermen compared the seatrout HSI results to their collective expertise and concluded that the HSI maps portrayed a reasonable depiction of the potential distribution of spotted seatrout in Pensacola Bay.

In order to test model performance and transferability, SI values developed in Pensacola Bay were applied to 10 years (1987 - 1996) of FIM data collected by the Texas Parks and Wildlife Department (TPWD) in Galveston Bay, Texas. Juvenile seatrout data from TPWD bag seine samples (N=1,808) were used to test juvenile HSI model performance, while gill net samples from 1994 - 1996 (N=268) were used to assess the adult HSI model. The TPWD data did not include the presence or absence of EV or SAV in their samples, therefore, only SI values for dissolved oxygen content, salinity, and temperature were applied. Overall, 94% of the bag seine samples were classified as either optimum or high suitability and these samples comprised almost 98% of seatrout captured by this gear type. Moderate suitability was classified for 108 samples and no samples were ranked as low suitability. Eight samples were classified as unsuitable.

Mean bag seine CPUE's were compared to mean HSI values to examine the efficacy of the model predictions. Linear regression and Analysis of Variance (ANOVA) results revealed a significant positive relationship between mean HSI value and mean bag seine CPUE (Figure 7a). Although vegetated habitat SI values were not applicable to the TPWD FIM data, the model performed adequately using the critical environmental variables in determining seatrout distribution in Galveston Bay. Minello (1999), determined that juvenile seatrout densities were greater in shallow, marsh edge and seagrass habitats in Texas and Louisiana estuaries. Numerous authors (Moody, 1950; Reid, 1954; Tabb, 1958; McMichael and Peters, 1989; Helser et al., 1993) also support these findings, thus emphasizing the importance of vegetated habitats as nursery grounds for juvenile spotted seatrout.

Adult SI values (dissolved oxygen, salinity, temperature) from Pensacola Bay were applied to the Galveston Bay gill net CPUE data. HSI values for these samples consisted of 20% moderate, 49% high, and 31% optimum. No samples were classified as either low or unsuitable, and may be a reflection of temporal bias. TPWD gill net monitoring only occurred during April - November thus, lower HSI values might be expected in the cooler months as estimated from the literature (Table 1). Regression of mean gill net CPUE's and mean HSI values (Figure 7b) reveal similar results as to those observed with juveniles - mean CPUE values were positively correlated with mean HSI values.

CHARLOTTE HARBOR/TAMPA BAY

Fisheries scientists from Florida Department of Environmental Protection (FDEP) and CCMA/BP collaborated to develop quantitative HSI models for spotted seatrout in Charlotte Harbor and Tampa Bay, Florida. The objectives of this research were to explore and implement various HSI modeling techniques and to assess the transferability of models developed in one estuary and applied to adjacent estuarine systems. For a more detailed description see Rubec et al. (1999).

In this study, Charlotte Harbor and Tampa Bay FIM data, collected from 1989 to 1997, were used to develop spotted seatrout HSI models. Spotted seatrout CPUE data were collected by numerous gear types with various mesh sizes. As such, CPUE's were standardized across all gear types that exhibited high catch rates of juvenile seatrout ranging from 10 - 119 mm standard length.

Coyne and Christensen (1997) described quantitative approaches to derive suitability functions from species abundance and habitat data. Three methodologies were used to develop seatrout suitability indices in Charlotte Harbor and Tampa Bay:

<u>Cumulative frequency method</u> - This method was used to determine biologically relevant environmental ranges for spotted seatrout HSI modeling. Catch data from the study areas were plotted in a frequency of occurrence histogram for each environmental variable and a frequency score was calculated for each variable increment (SAS, 1995). The frequency scores were then plotted against their respective environmental variable (Figure 8a). Portions of the plot with the greatest slope represent greater frequency of occurrence, while slopes approaching zero represent lower frequency of occurrence. Straight lines were drawn through portions of the curve with linear relationships (Figure 8b) to identify biologically relevant ranges. The slope of each line was determined using linear regression and suitability value's were calculated by dividing each slope by the maximum slope observed, then scaled from 0 - 10 for each environmental data set.

Range-Mean method - This method was similar to the cumulative frequency method, however, mean CPUE values were used to generate SI values for each biologically relevant range of the environmental variables. SI's were calculated by dividing the mean CPUE values by the maximum observed mean CPUE and scaling from 0-10 (Rubec et al., 1999).

Smooth-Mean method - This method was a revision of the range-mean method, where mean CPUE values were calculated and plotted along an environmental variable gradient. A polynomial regression curve was then fit to the mean CPUE values using JMP software (SAS, 1995). Predicted CPUE values along the curve were divided by the maximum observed CPUE and scaled from 0-10 to generate SI values (Rubec et al., 1999).

These methods were used to generate SI values for bottom salinity, bottom temperature and depth. Bottom type was a categorical variable (presence/absence) and SI values were determined by using the range-mean method.

Environmental Variables/GIS layers

Comparisons of the three suitability methods (cumulative frequency, range-mean, and smooth-mean) were made by plotting the suitability values across each variable gradient. The two CPUE methods yielded similar SI values for all environmental variables (salinity, temperature, depth), whereas SI values from the cumulative frequency method exhibited prominent differences. Consequently, habitat suitability maps were developed using the mean CPUE methods. Figure 9 displays the SI values for the range-mean for Tampa Bay and Charlotte Harbor. Table 2 provides the smooth-mean polynomial regression SI equations for salinity, temperature, and depth for Tampa Bay and Charlotte Harbor.

Environmental data (salinity, water temperature, depth, and bottom type) taken concurrent with biological samples were used exclusively to develop suitability indices. These data were also used to create the habitat grids for use in the GIS modeling process.

Habitat suitability maps were created for Charlotte Harbor during the fall season using salinity, temperature, depth, and bottom type SI functions. Four maps were derived using the two mean CPUE methods: two using Charlotte Harbor SI functions and two using SI functions transferred from Tampa Bay. Habitat suitability maps were computed in ArcView Spatial Analyst using the geometric mean formula (equation 1) for each cell across the environmental grids. Resultant grid cell HSI values were categorized into four classes: low (0.0-1.9), moderate (2.0-3.9), high (4.0-5.9), and optimum (6.0-10.0). Model performance was tested by superimposing the point data from the FIM samples over the predicted range-mean and smooth-mean HSI maps. The points were then assigned an HSI value according to the zone it resided in. Comparisons of mean CPUE and mean HSI value were then used to test the performance the suitability functions.

Habitat Suitability Results

The range-mean and smooth-mean models using Charlotte Harbor SI functions yielded similar patterns for the continuous habitat variables (depth, salinity, temperature). Highest juvenile spotted seatrout suitability indices occurred at mid-range salinities (15-25 ppt), high temperatures (>26˚ C), and shallow depths (<1.5 m). Optimum suitability was observed in the SAV bottom type category (Figure 10). Similar results occurred when the models developed from Tampa Bay FIM data were applied to the Charlotte Harbor environmental grids. SI functions were consistent between the two methods, but differed in the areal extent of HSI zones.

Model performance of the Charlotte Harbor derived SI functions and transferred SI functions from Tampa Bay revealed that the smooth-mean model performed as expected; increasing mean CPUE with increasing mean HSI value (Figure 11). The range-mean method did not exhibit a consistent positive correlation for either set of SI models.

Chi-square tests were used to compare the resultant HSI maps developed with SI functions from both estuaries. The range-mean model, using Charlotte Harbor SI values, estimated significantly different ($p<0.001$) seatrout HSI zones than the model transferred from Tampa Bay. In contrast, estimated HSI zone areas developed from the smooth-mean models from both estuaries were not significantly different ($p >0.05$).

In summary, the two HSI approaches based on different levels of available data agree with published literature which describe juvenile spotted seatrout distribution (McMichael and Peters, 1989; Killam et al., 1992; Christensen et al., 1997; Patillo et al., 1997). Optimum and high suitability areas for juvenile and adult spotted seatrout were observed in shallow waters containing SAV. Predicted areas of high suitability for adult spotted seatrout extended into deeper waters as compared to juveniles. This result also agrees with the literature as adult spotted seatrout are mid-water to surface piscivores and are not as dependent on the shallow, vegetated habitats which juveniles utilize as nursery habitats (Darnell, 1954; Johnson and Seaman, 1986). Depth was not considered in the modeling approach for both adult and juvenile spotted seatrout in Pensacola Bay. This may be a reasonable assumption for adults, which are more solitary and mobile in nature; however, numerous authors have cited that juvenile spotted seatrout and other estuarine dependent species concentrate in shallow, vegetated nursery areas that foster survival and/or growth (Lassuy, 1983; Boesch and Turner, 1984; Chester and Thayer, 1990; Minello, 1999). Rubec et al., (1999) calculated high juvenile seatrout SI values in shallow waters (0.4 - 1.6 m) based on Charlotte Harbor and Tampa Bay FIM data. Marsh and submerged aquatic vegetation are typically located in shallow depths throughout Gulf of Mexico estuaries and may act as a surrogate for depth in the models.

RECOMMENDATIONS FOR MANAGERS

The HSI modeling approach has been designed to be simplistic and can be modified and applied with minimal resources (Rubec et al., 1999). The SI continuum approaches can provide fisheries managers an assessment tool that focuses on habitat and ecosystem dynamics. Managers must determine what level of effort and resources are necessary to answer their management questions. Thus, a combination of methods along the continuum may be required as most FIM datasets do not cover complete ranges of available habitats and exhibit disproportionate seasonal and spatial sampling effort.

The transferability of models from well studied estuaries to those with little or no FIM data are of increasing concern. Fisheries monitoring programs are demanding on financial and personnel resources, and this approach will benefit those states with numerous estuarine systems, such as Florida and Texas. The results from the two HSI methods discussed in this chapter are promising, but more research is needed to fully understand biological and environmental limitations.

HSI maps can be used in a broad range of assessments requiring information on habitat distribution and quality. Individual species maps can be used to identify areas of varying habitat quality, as discussed in this chapter. This approach can identify habitats or species that may be sensitive or vulnerable to environmental or anthropogenic impacts. The models discussed in this chapter predicted optimum habitats as those containing shallow waters and vegetation. These habitats comprise a very small proportion of the total available habitat in each system and should be considered important habitats for conservation.

Scenario analyses compare habitat suitability changes in response to changes in environmental conditions. For example, Christensen et al. (1997) examined potential changes of habitat suitability in Pensacola Bay by artificially altering freshwater inflow patterns. Little change was observed for spotted seatrout, but significant changes in habitat suitability were observed for eastern oyster (*Crassostrea virginica*) and white shrimp (*Farfantepenaeus setiferus*). Livingston et al. (2000) estimated eastern oyster mortality in Appalachicola Bay, Florida, in response to changes in freshwater inflow. Oyster biological data was linked to a three-dimensional hydrodynamic circulation model in a GIS to depict the spatial range of oyster mortality in response to varying rates of freshwater inflow.

As GIS technology and modeling techniques advance, many more opportunities will evolve to enhance fisheries management. The current methods appear to be adequate to predict spatial distributions, but cannot predict actual abundance (Rubec et al., 1999).

Clark et al., (in review) have developed a multivariate habitat model that examines the relationship between brown shrimp (*Farfantepenaeus aztecus*) abundance and habitat. Results indicated that small brown shrimp (10 - 100 mm) were most abundant in marsh and submerged aquatic vegetation within mid - high salinity (<15 ppt) areas of Galveston Bay. These results could be incorporated into the spotted seatrout HSI models to investigate species interaction. Post-larval and juvenile brown shrimp are important dietary components for juvenile spotted seatrout. An approach for assessing brown shrimp - spotted seatrout interaction could be attempted by using the HSI models for spotted seatrout and adding a measure of prey availability (i.e. brown shrimp density estimates from Clark et al., in review). Deeper understanding of the abundance/habitat relation will allow more sophisticated models to be developed and further support fisheries management.

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Table 1. Suitability index (SI) values for spotted seatrout in Pensacola Bay, FL.

HABITAT VARIABLE	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
SALINITY (PPT)																										
adult	0.2	0.2	0.2	0.2	0.2	0.2	0.4	0.4	0.4	0.4	0.8	0.8	0.8	0.8	0.8	0.8	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
juvenile	0.2	0.2	0.2	0.6	0.6	0.6	0.6	0.6	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	0.8	0.8	0.8	0.8	0.8
TEMPERATURE (C)																										
adult	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.6	0.6	0.6	0.6	0.6	0.8	0.8	0.8	0.8	1.0	1.0
juvenile	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.2	0.2	0.4	0.4	0.4	0.4	0.6	0.6	0.6	0.6	0.6	0.6	0.6	1.0	1.0	1.0	1.0	1.0	1.0
D.O. (mg/l)																										
adult	0.0	0.0	0.0	0.6	0.6	0.6	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0											
juvenile	0.0	0.0	0.0	0.6	0.6	0.6	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0											
DEPTH (m)																										
adult	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
juvenile	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x

HABITAT VARIABLE	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50
SALINITY (PPT)																									
adult	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8
juvenile	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4
TEMPERATURE (C)																									
adult	1.0	1.0	1.0	1.0	1.0	0.8	0.8	0.8	0.8	0.6	0.6	0.6	0.6	0.4	0.4	0.4	0.2	0.2	0.2	0.0	0.0	0.0	0.0	0.0	0.0
juvenile	1.0	1.0	1.0	1.0	1.0	0.8	0.8	0.8	0.8	0.6	0.6	0.6	0.6	0.4	0.4	0.4	0.2	0.2	0.2	0.0	0.0	0.0	0.0	0.0	0.0
D.O. (mg/l)																									
adult																									
juvenile																									
DEPTH (m)																									
adult	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
juvenile	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x

SAV (pres/abs)	Presence	Absence
adult	1.0	0.8
juvenile	1.0	0.6

Wetlands (pres/abs)	Presence	Absence
adult	1.0	1.0
juvenile	1.0	0.6

Substrate	Clay	Silt/Mud	Sand
adult	1.0	1.0	1.0
juvenile	1.0	1.0	1.0

SI = 1.0
SI = 0.8
SI = 0.6
SI = 0.4
SI = 0.2
SI = 0.0
x SI = 1.0, parameter not pertinent

Table 2. Polynomial regression suitability index (SI) equations for Charlotte Harbor and Tampa Bay derived from mean CPUE's across gradients of temperature, salinity, and depth. (CH = Charlotte Harbor, TB = Tampa Bay, T = temperature, G = salinity, D = depth. The coefficient of determination (r^2) is based on the fitted mean CPUE's (Rubec et al., 1999).

Location	Regression Equation	Coefficient
	Temperature (i = 1)	
CH	$S_1 = 0.0317758 - 0.00557T + 0.000298T^2 - 0.00000447T^3$	$r^2 = 0.582$
TB	$S_1 = 0.3478437 - 0.048949T + 0.0021345T^2 -0.000028T^3$	$r^2 = 0.602$
	Salinity (i = 2)	
CH	$S_2 = 0.0040184 - 0.000393G + 0.0001427G^2 + 0.00000654G^3 + 0.000000007896G^4$	$r^2 = 0.705$
TB	$S_2 = 0.0027424 + 0.0007294G + 0.000018G^2 - 0.000000903G^3$	$r^2 = 0.600$
	Depth (i = 3)	
CH	$S_3 = 0.00223614 + 0.0212379D - 0.019623D^2 + 0.0061119D^3 - 0.000792D^4 + 0.0000363D^5$	$r^2 = 0.604$
TB	$S_3 = 0.0041553 + 0.036787D - 0.035219D^2 + 0.0124316D^3 - 0.002082D^4 + 0.000167D^5 - 0.000005D^6$	$r^2 = 0.659$

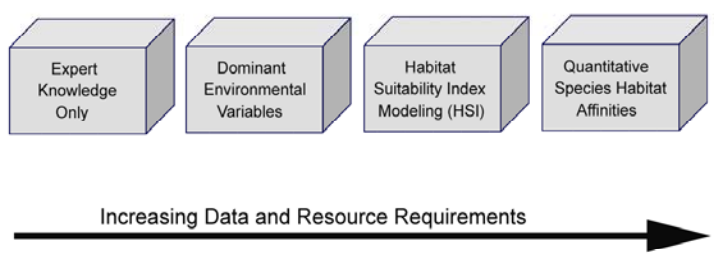


Figure 1. Continuum of approaches to evaluate the efficacy of SI derivation.

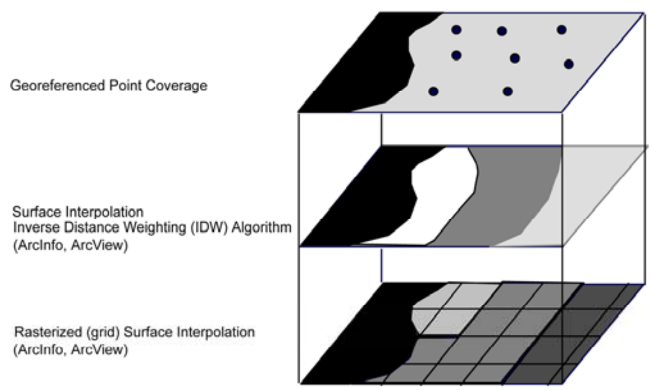


Figure 2. Conceptual model of grid map development.

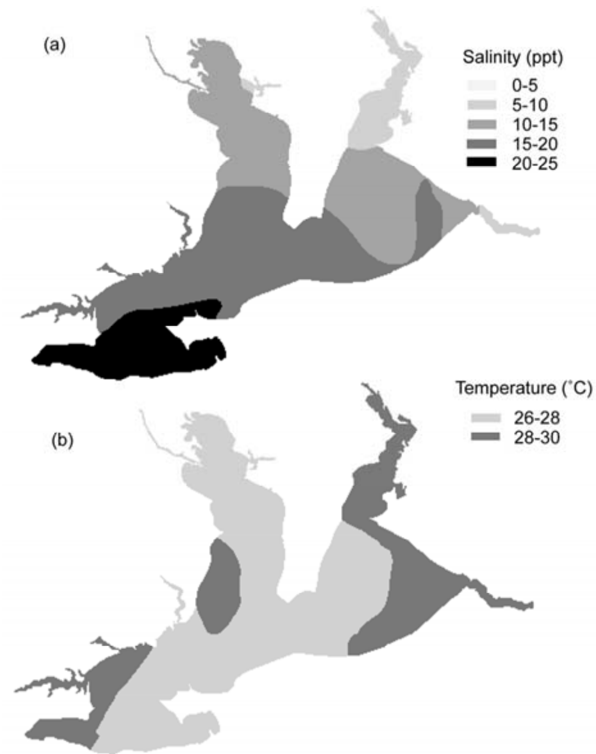


Figure 3. Salinity and temperature distribution during the increasing salinity time period (May - August) in Pensacola Bay, FL.

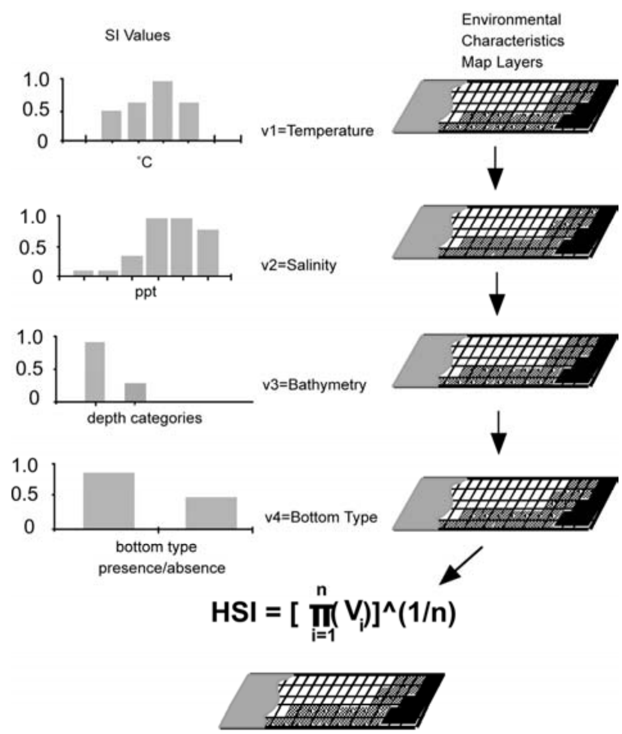


Figure 4.   Conceptual view of HSI map development.

Figure 6. Adult spotted seatrout HSI map calculated during the increasing salinity time period (May - August).

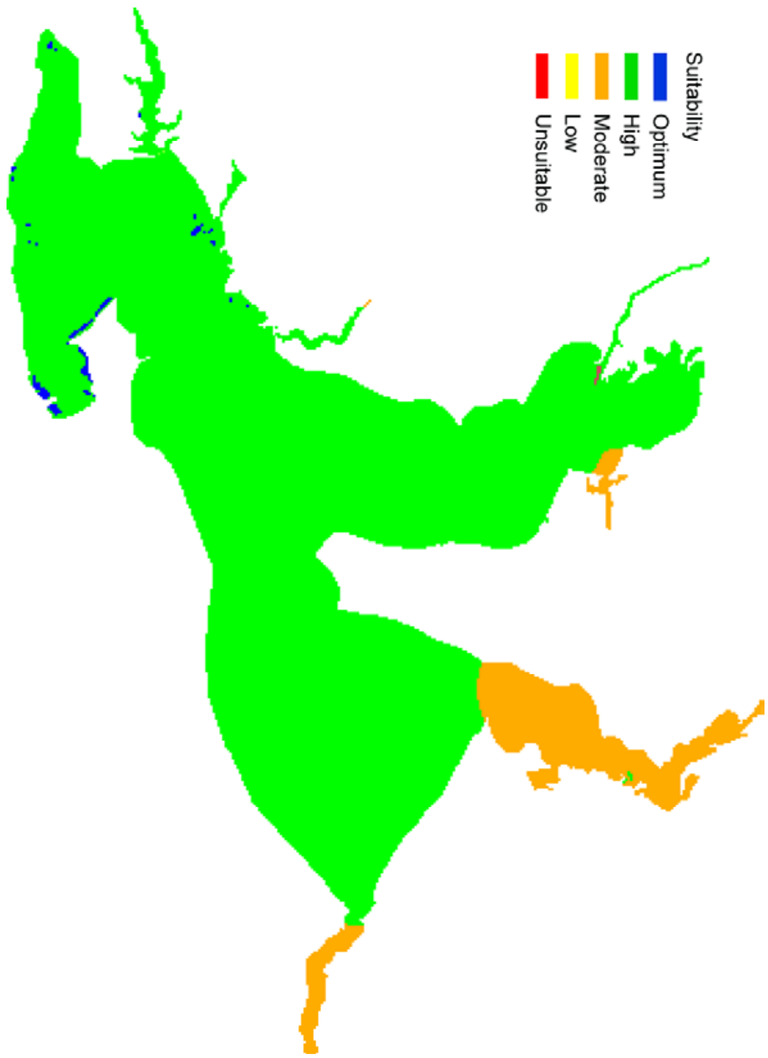
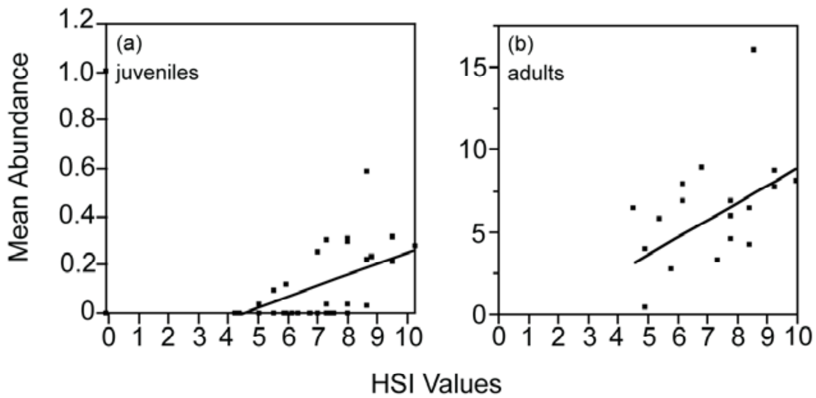


Figure 6. Adult spotted seatrout HSI map calculated during the increasing salinity time period (May - August).



Mean Abundance= -0.2047+0.0483 HSI		Mean Abundance= -1.5755+1.0466 HSI	
Rsquare	0.27	Rsquare	0.35
Observations	1809	Observations	268
Prob>F	0.0011	Prob>F	0.0085

Figure 7. Performance of SI values derived for juvenile (a) and adult (b) spotted seatrout for Pensacola Bay and applied to Texas Parks and Wildlife fishery-independent monitoring data from Galveston Bay.

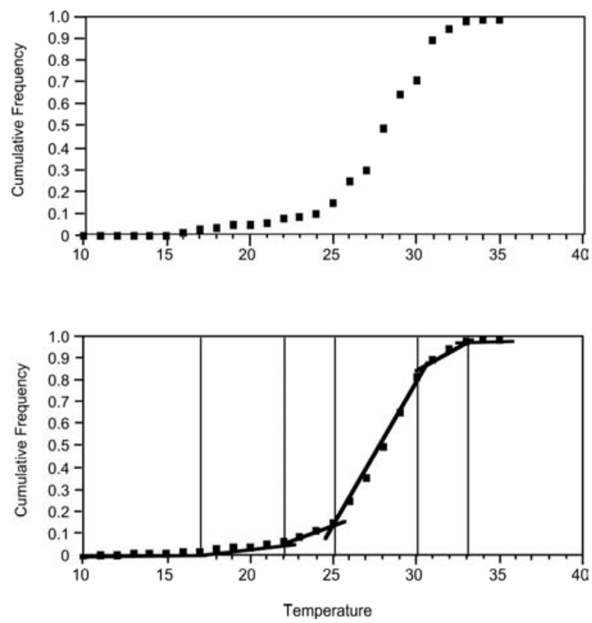


Figure 8. (a) Plot of cumulative frequency scores for spotted seatrout and salinity. Linear relationships within the cumulative frequency score curve. (b) Intersect points are used to delimit biologically relevant ranges.

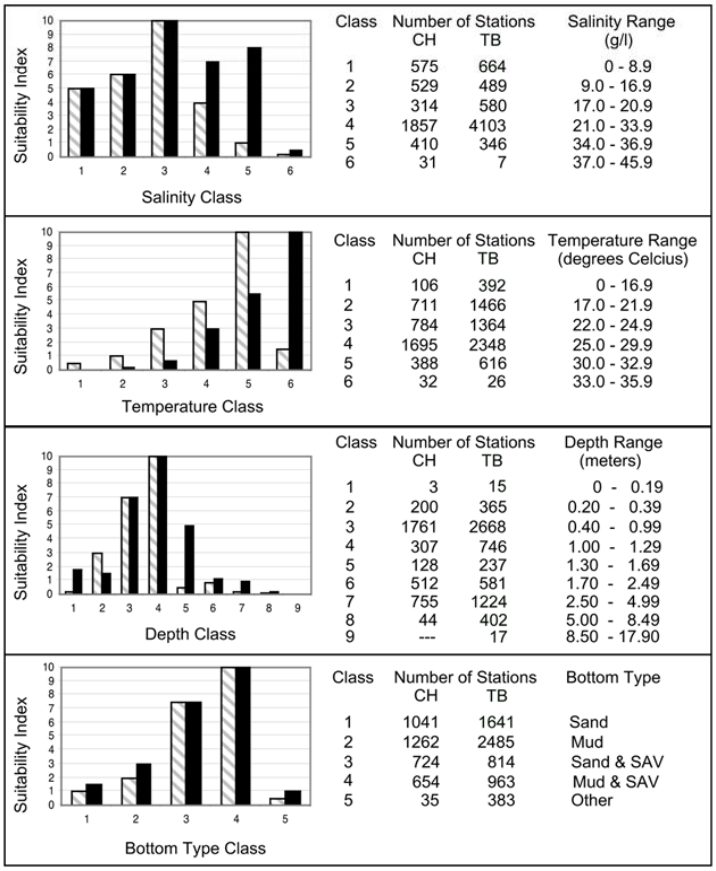


Figure 9. SI functions across biologically relevant gradients of salinity, temperature, depth, and bottom type for Charlotte Harbor and Tampa Bay using the range mean method (Rubec et al., 1999).

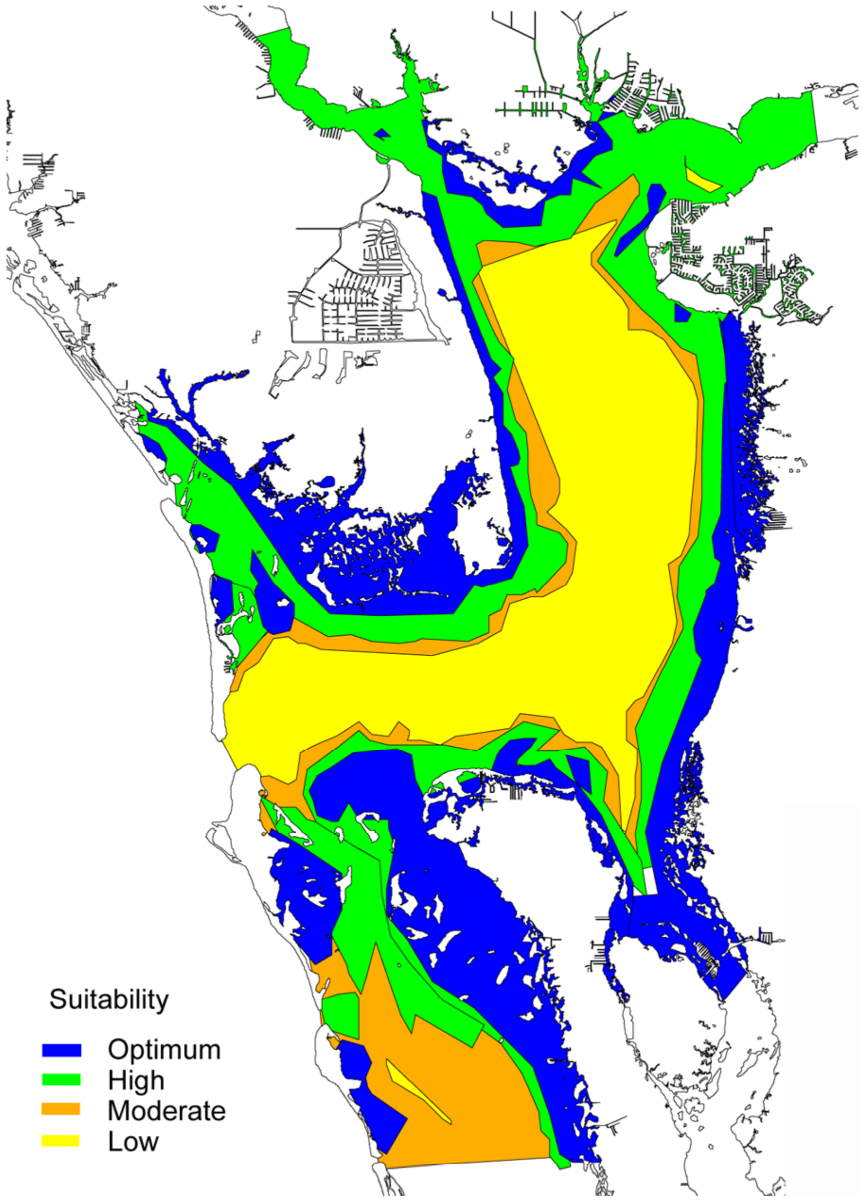


Figure 10. Juvenile spotted seatrout smooth-range HSI map using Charlotte Harbor FIM data (Rubec et al., 1999).

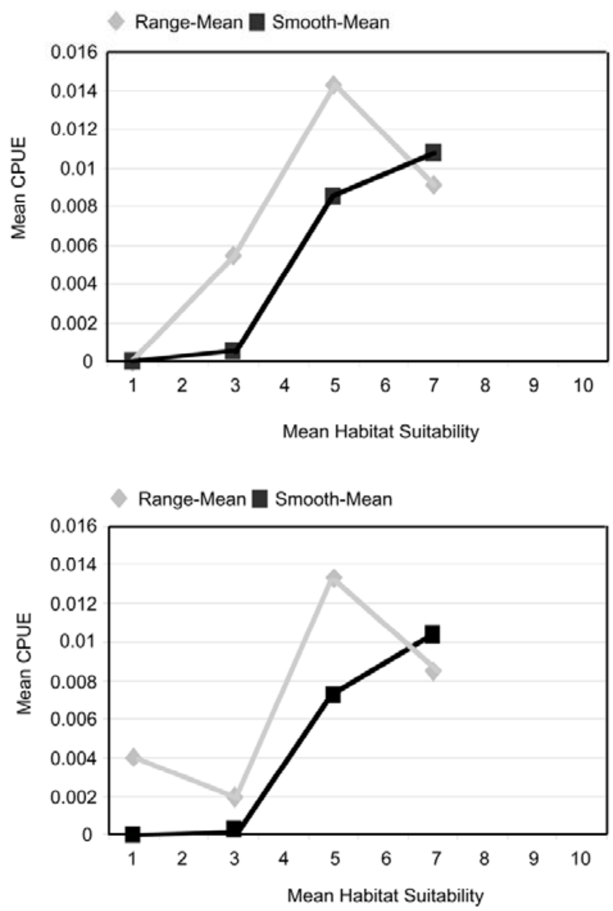


Figure 11. Comparison of mean CPUE values and mean HSI values by suitability zones using range-mean and smooth-mean SI functions from Charlotte Harbor and Tampa Bay (Rubec et al., 1999).